

The External Calibrator for Hydrogen Arrays

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ABSTRACT

We describe the External Calibrator for Hydrogen Observatories (ECHO)

1. Introduction

2. Design and Method

The ECHO system utilizes two networked machines which will henceforth be referred to as the ground station (GS) and the accumulation station (AS). Each station handles a different data stream, being GPS data for the GS and radio spectrum data for the AS.

For the calibration source, ECHO employs a X8 octoquad drone manufactured by 3DRobotics (3DR) with an onboard, programmable Valon 5007 synthesizer and a BicoLOG 30100 biconical antenna (see Fig. 1). To cover a large portion of the sky of the antenna under test (AUT), a spiral path along the surface of a sphere centered on the AUT with a radius greater than or equal to the AUT's far field distance is used. The waypoints are generated using a Healpix map, which divides the sky up into pixels with equal area according to a user specified parameter N_{side} , a power of 2, and a total pixel count of $N_{pix} = 12 \times N_{side}^2$. Ordered by pixel number from zenith to nadir, the altitude and azimuth of each pixel is obtained and converted to a waypoint, i.e. a list of waypoint number, latitude, longitude, and altitude. These obtained waypoints are then written to a waypoint file in order of position, starting at the horizon and ending at zenith. The internal GPS of the drone can then read in the generated waypoint file and autonomously follow these waypoints in flight. A region of interest (ROI) can be declared in the waypoint file prior to the first waypoint to force the drone to always face a specific region and keep a fixed yaw, i.e. a fixed BicoLOG polarization

To obtain the GPS position of the drone,

MAVProxy², a ground control station written in Python implementing the MAVLink communication protocol, is used to facilitate communication between the drone and APM Planner³ on the GS. Through a TCP connection with APM Planner (the server) and the drone (the client), APM Planner records the latitude, longitude, and altitude of the drone with an associated timestamp at which the position was measured every 300 ms. These positions, along with many other intermittent parameters and error messages, are continuously written to a telemetry log (tlog) file. This tlog is read and the realtime positions of the drone are recorded to a text file and made available for the AS via a queryable server setup on the GS.

In flight, the Valon synth is set to broadcast at a set frequency and power in the range of 137.5-4400 MHz. A Signal Hound (SH) BB60A 9 kHz to 6 GHz spectrum analyzer is used to measure the signal received by the AUT which records a radio spectrum in dB with an associated timestamp. The bandwidth of the recorded spectrum and its associated resolution can be modified based upon user input parameters pertaining to the number of FFT bins, the central frequency, and the bandwidth which cannot exceed 20 MHz. The radio spectrum data is then read in and each time associated with a spectrum is used to query the server on the GS. The output of which is an interpolated GPS position in the form of latitude, longitude, and altitude. If there is no valid GPS data at the query time, then -1 is returned for each of the aforementioned values. An accumulated file containing each query time and the associated latitude, longitude, altitude, and radio spectrum is then generated and used to produce

²<https://github.com/Dronecode/MAVProxy>

³<http://planner.ardupilot.com/planner2/index.html>

a FITS file containing the primary beam response of the AUT.

3. Calibration

The first full scale test of the ECHO system was done in August, 2015 at the National Radio Astronomy Observatory (NRAO) site in Green Bank, WV. Two dual-polarization dipoles (see Fig. 3) used in the development of a calibration technique utilizing the ORBCOMM satellite constellation (Neben et al. 2015) were used as the AUTs. With a dipole length of 90.4 cm and a Valon synth frequency of 137.554 MHz⁴, a flight radius of 100m was chosen, well into the far-field of the dipoles. Choosing a flight speed of 0.2 dam s⁻¹ and $N_{side} = 8$, each flight ECHO performed took 60 min. Four total flights were performed as each antenna contained two dipoles and thus needed to be tested with two flights, one with a polarization of the BicoLOG matching the polarization of one of the dipoles. This also allowed cross-polarization measurements of each antenna to be made.

3.1. Maps

The resulting maps can be seen somewhere... eventually...

3.2. Comparison to Orbcomm Ratio Maps

4. MWA Tile

4.1. Data

4.2. Systematic Variation

4.3. Comparison to Orbcomm Maps

5. Conclusion

6. Acknowledgments

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⁴Is this the right frequency



Fig. 1.— 3DR X8 octoquad drone prior to launch (left) and in flight (right). The Valon synth is contained in the black project box mounted on top of the drone. A copper plate, which acts as shielding from the electronics below, with the attached GPS magnetometer can be seen atop the project box. Beneath the drone, the BicoLOG antenna, which is blue in color, can be seen.

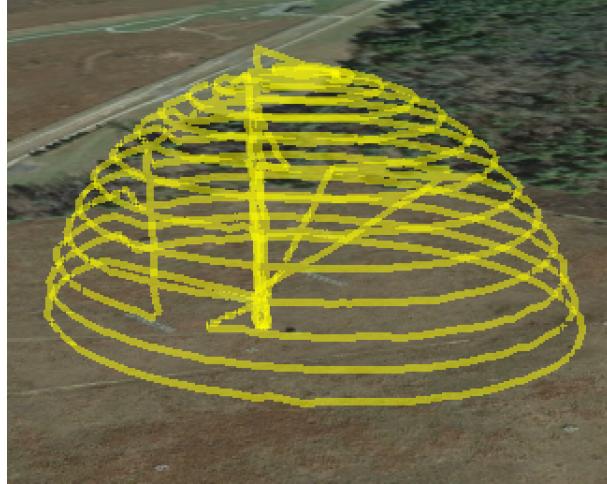


Fig. 2.— Actual flight path of drone in Green Bank, WV. The spiral pattern from horizon to zenith is generated from a Healpix map with parameter $N_{side} = 8$.



Fig. 3.— Dual-polarization dipole antenna seated on a $2\text{ m} \times 2\text{ m}$ ground screen. Located at the NRAO Green Bank, WV site and used for ECHO testing in August, 2015.